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Digestion and nitrogen balance using swine diets containing increasing proportions of coproduct ingredients and formulated using the net energy system

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Abstract

Rising feed expenditures demand that our industry pursues strategies to lower the cost of production. One option is the adoption of the net energy system (NE), although many producers are hesitant to proceed without proof that NE estimates are reliable. The objective of this experiment was to compare the apparent total tract digestibility (ATTD) of energy and nutrients and the N retention (NR) of diets formulated using the NE system with increasing quantities of co-product ingredients. The 5 dietary treatments included a control corn-soybean meal diet (CTL), the CTL diet plus 6% each of corn distiller's dried grains with solubles (DDGS), corn germ meal, and wheat middlings, and NE equal to the CTL diet by adding soybean oil (CONS- 18), the CONS-18 diet, without oil added, with NE content lower than CTL (DECL-18), CTL plus 12% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to CTL by adding soybean oil (CONS-36), the CONS-36, without oil added, with NE content lower than the CTL diet (DECL-36). Diets were formulated for both growing (40 to 70 kg; GP) and finishing (70 to 110 kg; FP) periods. Forty gilts (PIC 337 × C22 or C29; initial BW=38.5 ± 0.4 kg) were randomly assigned to treatment and received feed and water ad-libitum (8 pigs per treatment). For the last 13 d of the GP and FP, pigs were transferred to metabolism crates, where two total urine and fecal collections (d 4 to 6; d 11 to 13) were performed. The GP fed diets with coproduct ingredients had lower ATTD of DM, N and GE than those fed the CTL diet ($P < 0.050$). The ATTD of N and GE decreased progressively as co-product inclusion increased from 0 to 18 to 36% in the FP ($P < 0.010$). In the GP and FP, there were no differences in ATTD of DM, N or GE between the pairs of CONS and DECL-NE treatments ($P > 0.050$). The NR declined on all co-product diets on the GP ($P = 0.010$) and tended to decline in the FP ($P = 0.079$). There were no differences in NR between CONS and DECL diets with the same level of co-product inclusion ($P > 0.050$). In conclusion, digestion of diets containing up to 36% co-products and formulated using NE resulted in expected DE and ME values; NR of diets with coproducts was lower than on the simple corn-soybean meal CTL diet, which is not related to the accuracy of the energy estimations, but rather to other factors such as imbalances in the AA concentrations or to post-absorptive energy metabolism, factors not accounted by the current energy systems approach.

Keywords

Pig, net energy, corn DDGS, wheat middlings, corn germ meal, nitrogen retention

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RUNNING HEAD: Constant and declining net energy

Digestion and nitrogen balance using swine diets containing increasing proportions of co-product ingredients and formulated using the net energy system

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ABSTRACT

Rising feed expenditures demand that our industry pursues strategies to lower the cost of production. One option is the adoption of the net energy system (NE), although many producers are hesitant to proceed without proof that NE estimates are reliable. The objective of this experiment was to compare the apparent total tract digestibility (ATTD) of energy and nutrients and the N retention (NR) of diets formulated using the NE system with increasing quantities of co-product ingredients. The 5 dietary treatments included a control corn-soybean meal diet (CTL), the CTL diet plus 6% each of corn distiller's dried grains with solubles (DDGS), corn germ meal, and wheat middlings, and NE equal to the CTL diet by adding soybean oil (CONS-18), the CONS-18 diet, without oil added, with NE content lower than CTL (DECL-18), CTL plus 12% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to CTL by adding soybean oil (CONS-36), the CONS-36, without oil added, with NE content lower than the CTL diet (DECL-36). Diets were formulated for both growing (40 to 70 kg; GP) and finishing (70 to 110 kg; FP) periods. Forty gilts (PIC 337 × C22 or C29; initial BW=38.5 ± 0.4 kg) were randomly assigned to treatment and received feed and water *ad-libitum* (8 pigs per treatment). For the last 13 d of the GP and FP, pigs were transferred to metabolism crates, where two total urine and fecal collections (d 4 to 6; d 11 to 13) were performed. The GP fed diets with co-product ingredients had lower ATTD of DM, N and GE than those fed the CTL diet ($P < 0.050$). The ATTD of N and GE decreased progressively as co-product inclusion increased from 0 to 18 to 36% in the FP ($P < 0.010$). In the GP and FP, there were no differences in ATTD of DM, N or GE between the pairs of CONS and DECL-NE treatments ($P > 0.050$). The NR declined on all co-product diets on the GP ($P = 0.010$) and tended to decline in the FP ($P = 0.079$). There were no differences in NR between CONS and DECL diets with the same level of co-product

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inclusion ($P > 0.050$). In conclusion, digestion of diets containing up to 36% co-products and formulated using NE resulted in expected DE and ME values; NR of diets with coproducts was lower than on the simple corn-soybean meal CTL diet, which is not related to the accuracy of the energy estimations, but rather to other factors such as imbalances in the AA concentrations or to post-absorptive energy metabolism, factors not accounted by the current energy systems approach.

Keywords: Pig, net energy, corn DDGS, wheat middlings, corn germ meal, nitrogen retention

INTRODUCTION

Rising feed costs for swine demand that our industry pursue strategies to lower the cost of production. One of the most effective ways to respond to this demand is by including lower cost ingredients. However, one of the main challenges of including these materials is their lower NE concentration. This occurs mainly because of a different profile of their chemical constituents, especially in the carbohydrate fraction; starch is usually lower and molecules related to dietary fiber are usually higher in concentration than in corn. Pigs are able to increase feed intake when fed low NE diets, but there is an upper limit to this capacity (Oresanya et al., 2008; Beaulieu et al., 2009; Quiniou and Noblet, 2012). If feed intake does not rise, and this is entirely possible under many commercial conditions, low NE diets will result in poorer growth performance, compared to conventional ingredients (Quiniou and Noblet, 2012). To avoid this problem, NE concentration can be increased efficiently by adding a source of fat to the diet (Bakker, 1996), but this normally involves an increase in the cost. Therefore, to justify its use, added fat should enhance energy retention. In theory, diets with the same NE content should result in a similar tissue accretion despite having different chemical composition. In contrast, diets with a declining NE should result in a poorer tissue accretion.

The first objective of this experiment was to compare apparent total tract digestibility (ATTD) of DM, N and GE in diets containing an increasing level of distiller grains, corn germ, and wheat middlings and formulated to a constant or declining NE value. The second objective was to test if N retention (NR) is equal when diets are formulated to an equal NE concentration.

MATERIALS AND METHODS

All experimental procedures adhered to guidelines for the ethical and humane use of animals for research, and were approved by the Iowa State University Institutional Animal Care and Use Committee (number 12-12-7478-S).

Animals Housing and Experimental Design

This experiment was conducted at the Swine Nutrition Farm at Iowa State University (Ames, IA). Two groups of 20 gilts (initial BW 38.5 ± 0.4 kg), the progeny of PIC 337 sires × C22 or C29 dams (Hendersonville, TN), were randomly assigned to 1 of 5 treatments for 2 growth periods: a growing period (GP) from 39 to 70 kg, and a finishing period (FP) from 70 to 110 kg (n = 8 pigs per treatment). Within each period, pigs were placed in individual pens for 21 d and then transferred to metabolism crates for 13 d. The average daily room temperature was 18°C and 16°C (for GP and FP, respectively). Each pen included a partially slatted concrete floor, an automatic dry self-feeder and a cup drinker. Each crate consisted of a fully slatted floor, stainless steel feeder, and a nipple drinker. Pigs had *ad libitum* access to feed and water during the entire experimental period.

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Data, Samples and Experimental Treatments

Prior to formulating the diets, samples of corn, soybean meal, corn distiller's dried grains with solubles (DDGS), corn germ meal, and wheat middlings were finely ground and analyzed (Table 1) at the Agricultural Experiment Station Chemical Laboratories (University of Missouri-Columbia, MO) and the Monogastric Nutrition Laboratory (Iowa State University, Ames, IA). Ingredients samples were ground through a 1 mm screen in a Retsch grinder (Model ZM1, Retsch Inc., Newton, PA) and tested for DM (Method 930.15; AOAC, 2007), starch (using total starch assay procedure K-TSTA 04/2009, Megazyme, Wicklow, Ireland), CP as N × 6.25 (method 984.13 A–D; AOAC, 2006), ADF and NDF (Van Soest and Robertson, 1979) and ether extract (method 920.39; AOAC, 2005).

Complete diets were manufactured using the previously tested ingredients and according to the following specifications (Tables 2 and 3): A control corn-soybean meal diet (CTL), the CTL diet plus 6% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the CTL diet by adding soybean oil (CONS-18), the CONS-18 diet, without oil added, with NE content lower than CTL diet (DECL-18), the CTL diet plus 12% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the CTL diet by adding soybean oil (CONS-36), and the CONS-36, without oil added, with NE content lower than the CTL diet (DECL-36).

Amino acids, phosphorous and calcium levels were set at 6% above NRC 2012 requirements for both growing (40 to 70 kg) and finishing (70 to 110 kg) gilts. In this way, energy could be considered the only limiting factor for N retention. Additionally, titanium dioxide was included at 0.4% as an indigestible marker. All diets were provided in mash form.

Feed samples were collected at the feed mill at the time of mixing and again weekly during the feeding period.

While in metabolism crates, pigs had a 3 d adaptation period. Then, feces were completely removed twice daily during d 4-6 and d 11-13 from the metabolism crate and placed into a pre-labeled plastic bag. Total urine was collected twice a day during d 4-6 and d 11-13 by placing a metallic tray underneath the crate. This tray drained into a plastic jug containing ≈20ml of 6*N* hydrochloric acid (added before each collection to minimize N losses due to ammonia volatilization). Urine pH was measured at each collection to ensure a pH below 2.0. Total urine output was weighed, homogenized, filtered, and subsampled (10%). Once collected, urine and feces were immediately stored at -20°C until further processed.

At the end of the collection period, fecal samples were thawed at room temperature, homogenized, subsampled, dried in an oven at 105°C, and finely ground through a 1 mm screen in a Wiley mill (Model ED-5, Thomas Scientific Inc., Swedesboro, NJ). Feed samples were ground through a 1 mm screen in a Retsch grinder (Model ZM1, Retsch Inc., Newton, PA). Both fecal and feed samples were stored in plastic bags in desiccator cabinets while urine samples were subsampled in 250 ml aliquots and kept at -20°C until chemical assays were performed.

Samples of feed, urine, and feces were analyzed to determine the concentration of N by thermo-combustion (method 990.03, AOAC International, 2007; Leco TruMac N, LECO Corporation, St. Joseph, MI) with EDTA (9.56% N; Leco Corporation, St. Joseph, MI) used as a standard for calibration and was determined to be 9.58 ± 0.01. Acid hydrolyzed ether extract was analyzed (only for diets) using a SoxCap SC 247 hydrolyzer and a Soxtec 255 semiautomatic extractor, (FOSS North America, Eden Prairie, MN). Feed and fecal samples were analyzed for DM (method 930.15; AOAC, 2007); GE, determined using a Parr isoperibolic bomb calorimeter

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(Model 6200, Parr Instrument Co., Moline, IL). Benzoic acid (6,318 kcal/kg; Parr instruments, Moline, IL) was used as a standard for calibration and was determined to be 6,323 ± 2 kcal/kg. GE of urine was determined by calculation, as explained below. Titanium dioxide was determined in feed and feces using a Synergy 4 spectrophotometer (BioTek, Winooski, VT), according to the method of Leone (1973). Amino acid analyses of diets were determined by wet chemistry (Evonik-Degussa Laboratory, Kennesaw, GA) using an HPLC procedure after acid hydrolysis for most AA or following performic acid oxidation with acid hydrolysis for sulfur AA (method 994.12; AOAC International, 2002). Tryptophan content was determined after alkaline hydrolysis.

Calculations

Laboratory results from the ingredient assays as well as the ME values published in the NRC, 2012 were used to estimate NE according to equation 1-7 (NRC, 2012):

$$NE = (0.726 \times ME) + (1.33 \times EE) + (0.39 \text{ x } Starch) – (0.62 \times CP) – (0.83 \times ADF)$$

where energy is expressed in kcal/kg DM and other nutrients in g/kg DM.

All the remaining specifications of ingredients were taken from the NRC 2012 feed ingredient composition tables.

The ATTD of DM, N, and GE was calculated using the equation: ATTD, % = [100 – [100 × (% TiO_2 in feed / % TiO_2 in feces) × (concentration of component in feces / concentration of component in feed)]] (Oresanya et al., 2008).

Digestible energy was calculated by multiplying GE concentration by the ATTD of GE, ME was calculated by subtracting urinary energy from DE (calculation of methane loses were omitted in this calculation due to a lack of a reliable equation and its relatively small contribution to the calculation, (Patience, 2012). Urinary GE was calculated using the equation developed by Noblet and van Milgen (2004):

Urinary energy = 192 +31 × Urinary N

where urinary energy is in kJ/kg DMI and urinary N in g/kg DMI and then transformed to kcal using the conversion factor (1 kJ = 0.2390 kcal).

Nitrogen intake was calculated by multiplying N in the feed (DM basis) times DMI and N excreted in the urine was calculated by multiplying the average daily volume of urine times the average urinary N concentration. Nitrogen excreted in feces (DM basis) was calculated by multiplying the N intake times the ATTD of N. Nitrogen excretion was calculated as the sum of N excreted in urine and N excreted in the feces per day. Finally, N retention was calculated by the difference between N excretion and intake.

Statistical Analysis

The UNIVARIATE procedure of SAS (SAS Inst., Inc., Cary, NC) was used to test for normality and extreme values. The MIXED procedure of SAS was used including treatment as fixed effect and replicate as a random effect in the model. Multiple comparisons among treatments were determined using the protected LSD test, when the overall treatment effect was significant. Differences among treatments were considered statistically significant with $P \leq 0.05$ and trends with $P > 0.05$ to $P \leq 0.10$. Since they were housed individually, pig was the experimental unit in all instances.

RESULTS

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Chemical analysis of ingredients for CP, starch, EE, ADF and NDF (Table 1) were in general agreement with those reported by NRC, (2012). Consequently, computed ingredient NE values were very close to those reported by the NRC, (2012).

ATTD of DM, N and GE

In the GP, feeding diets with coproduct ingredients resulted in lower ATTD of DM, N and GE compared with the CTL diet (Table 4; $P < 0.050$). In addition, there were no differences in these same measures between the constant and the declining NE treatments within the same level of co-product inclusion ($P > 0.050$). In the FP, the ATTD of DM, N and GE decreased progressively from 0 to 18 to 36% co-product inclusion (Table 5; $P < 0.010$). There were no differences in these same measures between the constant and the declining NE treatments with the same level of co-product inclusion ($P > 0.050$).

Energy Values

Determined GE in the GP was greater in diets with co-products than the CTL diet. Additionally, CONS-18 and CONS-36 diets were higher in GE than DECL-18 and DECL-36 diets due to the added fat (Table 6). As expected, the determined DE and calculated ME and NE were similar ($P > 0.050$) in CONS-18 and CONS-36, but lower ($P < 0.050$) in DECL-18 and DECL-36 treatments compared with the CTL diet.

Determined GE in the FP was greater in diets with co-products than the CTL diet (Table 7). In addition, CONS-18 and CONS-36 diets were higher in GE than DECL-18 and DECL-36 diets. Determined DE and calculated ME and NE were similar ($P > 0.050$) in CONS-18 and CONS-36, but lower ($P < 0.050$) in DECL-18 and DECL-36 treatments compared with the CTL diet. Within co-product diets, CONS-18 was not significantly different in determined DE and

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calculated ME and NE than DECL-18 (*P* > 0.050), but for these same variables CONS-36 was greater than DECL-36 (*P* < 0.050).

Nitrogen Balance

In the GP, daily N intake tended to be higher on DECL-36 than in pigs fed the CONS-18, Const-36 and the CTL diet (Table 6; *P* = 0.077), while DECL-18 represented an intermediate value. Total daily N excretion was higher in pigs fed DECL-36 than the rest of the treatments (*P* < 0.050), except for DECL-18 that presented an intermediate value. Daily fecal N excretion was higher in pigs fed DECL-36, CONS-36 and DECL-18 than those fed the CTL diet, while CONS-18 presented an intermediate value. Total daily urinary N excretion was not different among treatments (*P* = 0.115). Total daily N retention tended to differ among treatments (*P* = 0.066); retention was similar for pigs fed DECL-18 and DECL-36 compared with the CTL diet (*P* > 0.050), but it was lower for CONS-18 and CONS-36 diets (*P* < 0.100).

The percentage of N excreted was lower in pigs fed the CTL diet than the rest of the treatments (*P* < 0.050); alternatively, the percentage of N retained was higher in pigs fed the CTL diet than pigs on the rest of the treatments (*P* < 0.050). Partitioning of the N excretion shows that the CTL diet resulted in lower fecal N excretion than the rest of the treatments (*P* < 0.050), while urinary excretion was similar among treatments (*P* > 0.050).

In the FP, daily N intake was higher in pigs fed CTL, DECL-18 and DECL-36 compared with CONS-18 and CONS-36 (Table 7; *P* < 0.050). Total daily N excretion was higher in pigs fed DECL-36 and DECL-18 than those fed any of the other treatments (*P* < 0.050). Daily fecal N excretion was highest in pigs fed DECL-36, followed by CONS-36 and DECL-18 and lowest for CONS-18 and the CTL diet (*P* < 0.050). Total daily urinary N excretion tended to differ among treatments (*P* = 0.076), being greater for DECL-18 than CONS-18 and CONS-36 (*P* < 0.050),

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and intermediate for DECL-36 and the CTL diet. Daily N retention was greater for pigs fed DECL-18, DECL-36 and the CTL diet ($P > 0.050$), than for CONS-18 ($P < 0.050$). The CONS-36 was intermediate between CONS-18 and DECL-16 ($P > 0.050$), but lower than DECL-18 and the CTL diet ($P < 0.050$).

Percentage of N excreted tended to differ among treatments ($P = 0.079$), being lower in pigs fed the CTL diet than the rest of the treatments ($P < 0.050$); in the opposite way the percentage of N retained tended to be higher in pigs fed the CTL diet than pigs on the rest of the treatments ($P < 0.050$).

DISCUSSION

Dietary GE concentration is determined by the profile of carbohydrates, lipids and proteins (NRC, 2012). In this experiment, the difference of GE among diets was mainly attributed to the increase in the proportion of fat and protein, which are more energy dense (9.4 and 5.6 calories per gram, respectively) than carbohydrates (4.2 calories per gram; Patience, 2012). On the other hand, the change in the proportion of the carbohydrate fractions (higher dietary fiber and lower starch for diets with co-products) did not alter the GE concentration because the GE values of fiber and starch are similar (4.2 calories per gram; NRC, 2012). As expected, the increase in GE between the constant and declining NE diets is explained by the higher fat content provided by the addition of soybean oil to the constant NE diets. These diets serve as an excellent illustration of how similar values for DE, ME and NE can be achieved when dietary components, such as starch, fiber, fat and protein differ. However, since N balance was not closely linked with either DE, ME or NE concentration in the diet, the accuracy or inaccuracy with which these energy systems predict performance is revealed (Birkett and deLange, 2001b), especially when diet composition changes in the manner reflected in this experiment.

Usable energy derived from GE is determined in part by the digestibility of dietary constituents (Bakker, 1996). Measurement of the ATTD of GE confirmed that the non-digested fraction is larger in diets with co-products, which is mainly attributed to the increase in the fiber fraction (Le Goff and Noblet, 2001; Urriola and Stein, 2010; Gutierrez et al., 2013). As a dietary component, fiber has a poor source of energy because its digestion is low and dependent on the gut microflora and the associated production of short chain fatty acids. Therefore, digestion of fiber is not only limited in pigs (Zijlstra et al., 2012; Zhang et al., 2013), but it is also dependent on the microbiota that fluctuates according to various environmental influences (Issacson et. al, 2012; Chen et. al, 2014). Additionally, the production of short chain fatty acids by fermentation represents an energy loss since during microbial synthesis, energy is released as heat (Kohn, 2008). Therefore, there is a large proportion of energy from fiber which is not utilized by the pig. Other effects on digestibility attributed to fiber are increased endogenous secretions (Schulze et al., 1995), reduction of the digestion and absorption of other dietary components (Milgen, 2006) or the increase of N from microbial origin (Xiao et al., 2015). For example, in this experiment, the ATTD of N decreased in the same fashion as the ATTD of GE, suggesting either an interference by fiber of AA absorption, higher AA endogenous loses as co-product levels increased, an increase of N fixation in the large intestine or a combination among any of these factors. This result is in close agreement with Gutierrez et al. (2013), who obtained similar findings in terms of apparent N and energy digestion with increasing levels of corn bran with solubles with constant and declining NE diets.

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The addition of fat to the diet is essential if the goal is to equalize the net energy concentration of diets. Fats are expected to increase the digestibility of GE due to its highly digestible composition (NRC, 2012), and an associated increase in retention time of digesta in the gastrointestinal tract (Valaja and Siljander-Rasi, 2001). In this experiment, the inclusion of soybean oil (1.7 and 3.3%) failed to increase the ATTD of GE (constant NE diets vs declining NE diets). Increased digestion of GE has been reported by Kil et al. (2011, 2013) with a higher level of added soybean oil (5, 8 and 10%). However, Jørgensen et al. (1993), with fat levels closer to the range used in this current study (0.5 to 3% of added soybean oil), reported no significant differences in the ATTD of GE. Therefore, a possible reason for no change in the ATTD of GE with added fat is the small quantity added. Nonetheless, the DE content of the diets with added fat were similar in both the GP and the FP in the constant NE diets, but this would have been due, in part, to the higher GE of the diets. The objective of the diet formulations - to maintain constant DE, ME and NE through the addition of fat to the higher fiber diets – therefore was accomplished in both GP and FP.

Dietary energy and protein are closely related because protein is a source of energy, because energy is needed for protein turnover and deposition, and because protein is part of the energy retained in the body (Boorman, 1980). Lawrence et al., (1994) reported a close relationship between N retention and DE. In this experiment, constant NE diets were formulated to a same SID Lys:NE ratio, as well as a similar NE, to achieve the same level of N retention. However, N retention in growing and in finishing pigs was lower when pigs were fed diets with coproducts compared to pigs fed a corn soybean meal diet. There are 2 possible explanations: an insufficient AA supply or an insufficient energy supply.

Amino acid analysis of the diets was performed in order to confirm SID specifications were achieved. Although the experimental diets were formulated to be equal in SID Lys, actual SID Lys estimations were slightly lower in diets with co-products, especially for the CONS-36 diet in growing pigs. Therefore, a possible reason for a lower N retention could be related to a slightly lower SID values for Lys in the constant NE diets than the control diet. Another reason related to the AA supply is connected to the N flow; the SID values used in diet formulation do not account for the specific N losses driven by an increase in the fiber fraction discussed previously, creating an increase in AA requirements. However, the percentage of excreted urinary N did not decrease to compensate for the increase of nitrogen lost in the feces in the diets with coproduct addition. This suggested that energy-related reasons for the decrease in the percentage N retention is more likely. An example of this relates to the regulation of protein synthesis in skeletal muscle. Suryawan et al. (2007) suggested that protein synthesis in skeletal muscle is associated with increased activation of insulin-signaling components after a postprandial increase in glucose, indicating that a requirement exists for sufficient glycemic and insulinemic responses for efficient N retention (Drew et al., 2012). In this experiment, coproduct diets were considerably lower in starch content than the corn soybean meal diet. However, to the best of our knowledge, it has not yet been shown that starch levels employed in this study would be insufficient to induce glycemic and insulinemic responses. Therefore, a more likely energy related-explanation could be errors in the equations used to estimate dietary NE levels.

Finally, another possibility to consider are the differences in the actual energy supply across diets. It is entirely possible that neither the DE, ME or NE systems accurately reflect the quantity of energy made available to the tissues for maintenance and growth functions. Ultimately, the energy supplied to the pig depends to a large extend on the variable post-

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absorptive metabolism factors that may not be accurately accounted for by the current energy system approach (Milgen, 2006). To provide a more reliable and predictable response to the energy supply, a more mechanistic, situation-based model is rquired (Birkett and deLange 2001a).

In conclusion, the digestion of diets containing increasing levels of co-products and formulated to a constant NE concentration failed to elevate ATTD of DM, GE and N above that of diets uncorrected for NE. However, due to an initial increase in GE, these diets meet an expected equivalence of DE, ME and NE concentration. On the other hand, N retention was not maintained, an unexpected outcome. This response may be related to an inadequate AA supply, to errors in the equations used to estimate NE or to the limitation of the NE system to account for the energy utilization of the post absorptive metabolism.

Implications

The ability of any energy system to accurately predict growth and nitrogen retention is suspect. However, it is believed that he NE system is superior to other systems in this regards (Schinckel et al., 2012; Acosta et al., 2015). The data reported herein support this belief, but also points to the fact that equivalence of NE does not necessarily lead to equivalence of performance. This could be due to inaccurate NE values for ingredients, to non-nutritive effects of ingredients or to the fundamental challenge of any energy system to accurately predict pig performance across extremely diverse diet ingredient composition.

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Table 1. Analyzed ingredient composition and calculation of NE values for the ingredients utilized in the experimental diets (as-fed basis)

Ingredient	Corn	Soybean meal	Corn DDGS[1]	Corn germ meal	Wheat middlings
Composition, %					
DM	86.7	89.5	91.1	89.2	89.3
CP	8.6	47.2	27.2	25.0	17.1
EE	3.5	1.5	10.0	3.0	3.8
Starch	61.1	2.0	4.1	18.0	14.1
ADF	1.6	4.0	12.1	9.7	11.8
NDF	5.9	5.7	24.5	36.5	35.5
NE, Mcal/kg					
Calculated[2]	2.713	1.958	2.298	1.873	2.020
NRC, 2012[3]	2.672	2.087	2.384	1.888	2.113

[1]Distiller's dried grains with solubles.

[2]From NRC 2012, Equation [1-7].

[3]Energy values from NRC, table 17-1; corn, yellow dent (p. 261), soybean meal, dehulled, solvent extracted (p. 332), corn DDGS >10% oil, corn germ meal (p. 271), and wheat middlings (p. 357).

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Table 2. Ingredient composition of experimental diets[1]

	Growing pigs					Finishing pigs				
Ingredient, %	CTL	CONS -18	DECL -18	CONS -36	DECL -36	CTL	CONS -18	DECL -18	CONS -36	DECL -36
Corn	72.39	56.46	58.25	40.58	44.06	79.61	63.66	65.45	47.67	51.26
Soybean meal	23.90	20.40	20.27	16.89	16.64	16.95	13.44	13.31	9.93	9.68
Corn DDGS[2]	-	6.00	6.00	12.00	12.00	-	6.00	6.00	12.00	12.00
Corn germ meal	-	6.00	6.00	12.00	12.00	-	6.00	6.00	12.00	12.00
Wheat middlings	-	6.00	6.00	12.00	12.00	-	6.00	6.00	12.00	12.00
Soybean oil	-	1.66	-	3.32	-	-	1.67	-	3.33	-
L-lys HCl	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DL-methionine	0.06	0.01	0.01	-	-	0.03	-	-	-	-
L-threonine	0.08	0.06	0.06	0.05	0.05	0.07	0.06	0.06	0.05	0.04
Monocalcium phosphate	0.91	0.63	0.62	0.34	0.33	0.80	0.52	0.51	0.23	0.22
Limestone	1.15	1.27	1.28	1.40	1.41	1.03	1.15	1.16	1.28	1.28
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix[3]	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Titanium dioxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[1]CTL = corn soybean meal diet; CONS-18 = CTL plus 6% each of corn distiller's dried grains with solubles (DDGS), corn germ meal, and wheat middlings, and NE equal to the CTL diet; DECL-18 = same as CONS-18, without oil added, so that NE content is lower than CTL diet; CONS-36 = CTL plus 12% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the CTL diet; DECL-36 = Same as CONS-36, without oil added, so that NE content lower than CTL diet.

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[2]Distiller's dried grains with solubles.

[3]Vitamin premix provided the following (/kg diet): 4,900 IU of vitamin A; 560 IU of vitamin D_3; 40 IU of vitamin E; 2.4 mg of menadione (to provide vitamin K); 39 µg of vitamin B_{12}; 9 mg of riboflavin; 22 mg of d-pantothenic acid; and 45 mg of niacin.

[4]Mineral premix provided the following (/kg diet): 165 mg of Fe (ferrous sulfate); 165 mg of Zn (zinc sulfate); 39 mg of Mn (manganese sulfate); 2 mg of Cu (cooper sulfate); 0.3 ppm of I (calcium iodate); and 0.3 ppm of Se (sodium selenite).

Table 3. Chemical composition of experimental diets (as-fed basis)[1]

Item	Growing pigs					Finishing pigs				
	CTL	CONS -18	DECL -18	CONS -36	DECL -36	CTL	CONS -18	DECL -18	CONS -36	DECL -36
Energy and nutrients[2]										
ADF, %	2.10	3.90	3.90	5.70	5.70	2.00	3.70	3.80	5.50	5.60
NDF, %	5.60	10.30	10.40	15.10	15.30	5.70	10.40	10.50	15.10	15.30
Starch, %	44.70	37.07	38.16	29.47	31.59	48.97	41.33	42.42	33.66	35.85
AEE[3], %	2.91	4.89	3.30	7.01	3.79	3.02	5.11	3.51	7.10	3.89
CP, %	18.15	18.94	19.24	19.97	20.20	14.78	15.99	15.95	17.21	17.46
SID[4] AA %										
Lys	1.03	1.00	0.99	0.93	0.93	0.80	0.78	0.80	0.77	0.76
Thr	0.61	0.61	0.62	0.63	0.62	0.49	0.51	0.50	0.52	0.52
Met	0.28	0.31	0.25	0.26	0.26	0.23	0.21	0.22	0.24	0.23
TSAA	0.50	0.56	0.49	0.50	0.51	0.41	0.41	0.42	0.46	0.45
Trp	0.19	0.20	0.18	0.18	0.18	0.14	0.14	0.15	0.15	0.15
SID AA: Lys ratio										
Lys	100	100	100	100	100	100	100	100	100	100
Thr	60	61	63	67	67	61	65	63	68	68
Met	27	31	25	28	28	28	27	27	31	30
TSAA[5]	49	56	49	54	54	52	53	53	60	59
Trp	18	20	19	20	20	17	18	18	19	20
Ca, %	0.69	0.69	0.69	0.69	0.69	0.60	0.60	0.60	0.60	0.60
P total, %	0.55	0.58	0.58	0.61	0.61	0.50	0.52	0.53	0.55	0.56
STTD[6], P %	0.32	0.32	0.32	0.32	0.32	0.28	0.28	0.28	0.28	0.28
NE, Mcal/kg	2.43	2.43	2.35	2.43	2.27	2.49	2.49	2.41	2.48	2.32

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ME, Mcal/kg	3.25	3.29	3.20	3.33	3.15	3.26	3.30	3.21	3.34	3.17
NE:ME ratio	0.75	0.74	0.73	0.73	0.72	0.77	0.76	0.76	0.76	0.75

[1]Refer to footnote #1 in Table 2 for key to experiment code.

[2]NE, starch, NDF and ADF calculated from the results of ingredient analysis; ME, Ca, and total P and STTD P were calculated based on ingredient composition listed by the NRC (2012); CP and AEE were analyzed in the diets; SID amino acid levels were calculated from total amino acid analysis of each ingredient multiplied by the standardized ileal digestibility of each ingredient (NRC, 2012) and then calculated for total diet content.

[3]Acid hydrolyzed ether extract.

[4]Standardized ileal digestible.

[5]Total sulfur amino acids.

[6]Standardized total tract digestibility.

Table 4. Apparent total tract digestibility (ATTD) and energy content determined in the growing period[1,2]

Item	CTL	CONS-18	DECL-18	CONS-36	DECL-36	SEM	*P*-Value
ATTD, %							
DM	86.2[a]	82.3[b]	81.3[bc]	79.2[cd]	78.9[d]	0.6	0.002
N	84.9[a]	81.2[b]	79.8[b]	78.5[b]	78.4[b]	1.0	0.023
GE	85.3[a]	81.8[b]	80.5[bc]	79.2[bc]	78.1[c]	0.7	0.005
Energy Mcal/kg, DM							
GE	4.34	4.50	4.41	4.62	4.42	-	-
DE	3.70[a]	3.68[a]	3.55[bc]	3.66[ab]	3.45[c]	0.03	0.011
ME calculated[3]	3.53[a]	3.50[a]	3.38[b]	3.49[a]	3.27[b]	0.03	0.007
NE calculated[4]	2.66[a]	2.64[a]	2.53[bc]	2.62[ab]	2.45[c]	0.03	0.011

[a,b,c] Superscripts assess significant differences ($P > 0.050$) between dietary treatments.

[1]Data are least mean squares of 40 gilts, with 8 animals per treatment, analyzed using the Mixed procedure of SAS®.

[2]Refer to footnote #1 in Table 2 for key to experiment code.

[3]ME = DE-urinary energy. Urinary energy was calculated using Noblet and van Milgen (2004) equation: Urinary energy kJ/kg DMI = 192 + 31 × urinary N g/kg DMI, then transformed to kcal using the conversion factor (1 kJ = 0.2390 kcal).

[4]Noblet et al., (1994) equation 3: NE = 0.843 × DE – 463.

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Table 5. Apparent total tract digestibility (ATTD) and energy content determined for finishing period, diets contained 0, 18 or 36% of co-products, with a constant or declining NE content[1,2]

Item	CTL	CONS-18	DECL-18	CONS-36	DECL-36	SEM	*P*-Value
ATTD, %							
DM	87.9[a]	84.6[b]	85.0[b]	81.5[c]	81.3[c]	0.4	<0.001
N	86.2[a]	83.1[b]	83.1[b]	80.8[c]	79.7[c]	0.5	0.002
GE	87.1[a]	83.9[b]	84.3[b]	81.4[c]	80.6[c]	0.4	0.001
Energy Mcal/kg, DM							
GE	4.28	4.46	4.37	4.62	4.44	-	-
DE	3.72[ab]	3.74[ab]	3.68[b]	3.76[a]	3.58[c]	0.02	0.006
ME calculated[3]	3.56[a]	3.57[ab]	3.51[b]	3.58[a]	3.41[c]	0.02	0.004
NE calculated[4]	2.68[ab]	2.69[ab]	2.64[b]	2.70[a]	2.56[c]	0.02	0.006

[a,b,c] Superscripts assess significant differences ($P > 0.050$) between dietary treatments.

[1]Data are least mean squares of 40 gilts, with 8 animals per treatment, analyzed using the Mixed procedure of SAS®.

[2]Refer to footnote #1 in Table 2 for key to experiment code.

[3]ME= DE-urinary energy. Urinary energy was calculated using (Noblet and van Milgen, 2004) equation: Urinary energy kJ/kg DMI = 192 + 31 x urinary N g/kg DMI, then transformed to kcal using the conversion factor (1 kJ = 0.2390 kcal).

[4]Noblet et al., (1994) equation 3: NE = 0.843 x DE – 463.

Table 6. Effect of constant and declining NE formulated diets with 0, 18 and 36% of co-product addition on apparent N balance and retention in growing pigs[1,2]

Item	CTL	CONS-18	DECL-18	CONS-36	DECL-36	SEM	*P*-Value
N balance, g/d							
Intake	81.2	79.0	83.7	80.3	90.6	2.3	0.077
Total excreted	48.5^{b}	51.4^{b}	53.6^{ab}	50.8^{b}	59.6^{a}	1.7	0.034
Fecal	12.4^{c}	15.0^{bc}	17.0^{ab}	17.2^{ab}	19.8^{a}	0.8	0.009
Urinary	36.1	36.4	36.6	33.6	39.8	1.2	0.115
Net retained	32.8^{a}	27.6^{c}	30.1^{abc}	29.4^{bc}	31.1^{ba}	0.9	0.066
N balance, %							
Total excreted	59.4^{b}	65.2^{a}	64.0^{a}	63.4^{a}	65.6^{a}	0.7	0.009
Fecal	15.1^{b}	18.8^{a}	20.2^{a}	21.5^{a}	21.6^{a}	1.0	0.024
Urinary	44.3	46.4	43.8	41.9	44.0	1.1	0.198
Net retained	40.6^{a}	34.8^{b}	36.0^{b}	36.6^{b}	34.4^{b}	0.7	0.009

[a,b,c] Superscripts assess significant differences ($P > 0.050$) between dietary treatments.

[1]Data are least mean squares of 40 gilts, with 8 animals per treatment, analyzed using the Mixed procedure of SAS®.

[2]Refer to footnote #1 in Table 2 for key to experiment code.

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Table 7. Effect of constant and declining NE formulated diets with 0, 18 and 36% of co-product addition on apparent N balance and retention in finishing pigs[1,2]

Item	CTL	CONS-18	DECL-18	CONS-36	DECL-36	SEM	*P*-Value
N balance, g/d							
Intake	81.2^{bc}	73.7^{d}	86.2^{ba}	76.0^{cd}	87.7^{a}	1.7	0.009
Total excreted	53.0^{b}	51.8^{b}	59.3^{a}	54.1^{b}	61.3^{a}	1.4	0.017
Fecal	11.3^{c}	12.6^{c}	14.6^{b}	14.7^{b}	17.9^{a}	0.5	0.001
Urinary	41.7	39.2	44.6	39.4	43.4	1.2	0.076
Net retained	28.2^{a}	22.0^{c}	27.0^{a}	22.7^{bc}	26.5^{ba}	1.1	0.036
N balance, %							
Total excreted	65.0	70.0	68.8	70.6	69.7	1.1	0.079
Fecal	13.8^{c}	16.9^{b}	16.9^{b}	19.2^{a}	20.3^{a}	0.5	0.002
Urinary	51.2	53.2	51.9	51.5	49.5	1.2	0.393
Net retained	35.0^{a}	30.0^{b}	31.2^{ab}	29.4^{b}	30.3^{b}	1.1	0.079

^{a,b,c,d} Superscripts assess significant differences ($P > 0.050$) between dietary treatments.

[1]Data are least mean squares of 40 gilts, with 8 animals per treatment, analyzed using the Mixed procedure of SAS®.

[2]Refer to footnote #1 in Table 2 for key to experiment code.